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M3A system (2000–2005) – operation and maintenance

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Abstract. During the pilot phase of the Mediterranean Forecasting System (MFSPP) (2000 2003), a prototype observing system (Mediterranean Moored Multi-sensor Array – M3A) was designed, developed and operated in the Cretan Sea for continuous oceanographic measurements in real time. The main problems encountered were associated with biofouling, underwater and aerial communication and with the design of the surface buoy. In the second phase of the MFS project named Mediterranean Forecasting System Towards Environmental Predictions (MFSTEP) (2003–2005), the aim was to solve those problems and to consolidate the M3A. For the minimisation of biofouling a pilot field study was performed and the techniques of bromine solution and copper shielding were evaluated. Additionally, the oligotrophy of the Aegean Sea dictated the need to ignore factory calibrations and to perform site-specific laboratory calibrations of the sensors. This procedure was proved necessary and produced calibration coefficients that gave results comparable to the measurements obtained with the laboratory analysis method. During the approximately five years of operation, there were 13 scheduled and 15 emergency visits, with a total duration of 65 days. The acquired experience through the maintenance program proved that the continuous observation of such a very important system with a relative low cost is feasible.

1 Introduction

Oceans are very dynamic systems with active processes that include physics, chemistry and biology. The state of knowledge concerning our planet's oceans is built primarily upon the foundation of spatial exploration (Colwell, 2003). However, if these processes are to be understood, if new insights are to be gained, if quantitative models are to be validated satisfactorily, then observations are needed over the time scales appropriate to the dynamics of these processes (Colwell, 2003). Although the classical expeditions of short cruises, which focused on particular issues, will continue in the future, the rapid technological development and the need to explore ocean processes in time will revolutionize how ocean science will be conducted in the new millennium (Isern and Clark, 2003). This approach is not as some people think just monitoring, but instead is an active exploration of system dynamics in the time component. In the framework of EuroGOOS, a multi-national effort to develop an integrated operational monitoring and forecasting system for the Mediterranean Sea took place under the Mediterranean Forecasting System (MFS) project (Pinardi and Flemming, 1998). During the Pilot Phase of the Project (1998–2001), a significant element of the designed observing systems was the Mediterranean Moored Multi-sensor Array (M3A), a prototype observatory that was designed to form the basis of a permanent network of moored stations for continuous recording of open-ocean conditions in the Mediterranean Sea (Nittis et al., 2003). This first phase was devoted to the design, integration, deployment and pre-operational testing of the M3A station, the main features of which were i) moored in deep ocean (over 1000 m), ii) measuring the capability of physical parameters down to 500 m, biogeochemical parameters down to 100 m and air-sea interaction parameters at the surface, iii) raw data transmission in real time, and iv) low maintenance cost due to large autonomy and easy handling of the system. In this way, the system would be able to monitor the upper thermocline variability of the general circulation and biochemical processes in the euphotic zone, producing important oceanographic and atmospheric data for calibration/validation of ecological models, as well as for the development of data assimilation techniques (Petihakis et al., 2002; Triantafyllou et al., 2003b). For the location of the buoy a site at the Cretan Sea was chosen, since although close to the coast (24 nm north of Heraklion) it is an area of

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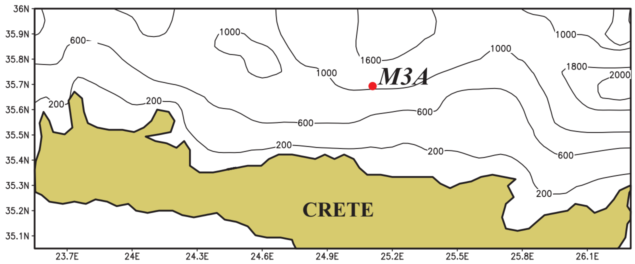


Fig. 1. Location of M3A station.

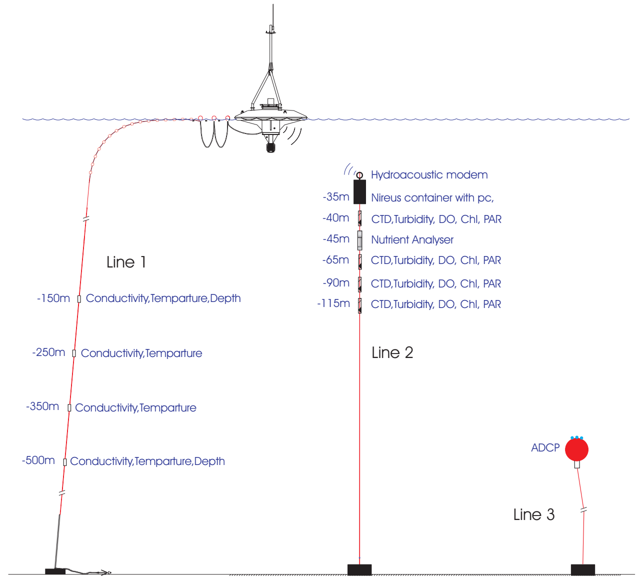


Fig. 2. M3A station setup.

open sea conditions, characterised as extremely oligotrophic where dense waters with intermediate and deep characteristics are formed (Balopoulos et al., 1999; Theocharis et al., 1999).

In the second phase of the MFS project named Mediterranean Forecasting System Towards Environmental Predictions (MFSTEP) (2001–2005), the aim was to consolidate the M3A and in particular i) to improve the functionality of the system and upgrade its capabilities (new underwater and satellite communications, new bio-optical measurements, new surface buoy) and ii) to expand the network with two more buoys, one in the Eastern and one in the Western Mediterranean Sea. The three stations together were designed to be the data producers for the validation of the basin scale current forecasts, serving as a subsurface extrapolation data set for surface satellite colour data and for assimilation into the ecosystem models.

2 M3A design and configuration

The station was deployed in the Cretan Sea (Fig. 1) in January 2000, with coordinates 35°39,627′ N and 24°59,080′ E at a depth of 1030 m with the 62 m R/V Aegaeo (http://www.hcmr.gr/english_site/services/shi_sub_rovs/aegaio.html). The system configuration involved a triple configuration (Fig. 2) and is described in detail by Nittis et al. (2003). To confront the M3A system problems that became emergent during the first phase, a number of modifications – upgrades were performed prior to redeployment at the second phase.

The buoy used in the pilot phase was an available one (Thanos and Pezirtzoglou, 1997), primarily designed as a wave directional data buoy of wave rider type. Since deep water oceanographic buoys, such as M3A, must operate as robust and reduced movement devices, the hull's movements were minimized by an appropriate floatation shape design. The new buoy was constructed to withstand wave heights up to 12 m with a significant flexibility in the design and with a modular construction (easily exchangeable parts, i.e. electronics, floaters, mast, underwater units and selectable dimensions). A new compass on board the buoy was installed, in order to reduce the power consumption, and the wind generator was replaced with a significantly lighter one with a better energy conversion coefficient. Several cable harnesses inside the instrumentation container were redesigned, in order to fulfill the worldwide standards while the meteorological package was enriched with new sensors (solar radiation, rainfall). Additionally, new underwater and satellite communication systems were implemented, i.e. satellite transceiver, mobile phones, under-water acoustic bi-directional modems, enabling two-way signal transferring IMC modems while the underwater hardwired network was embedded into the buoy container and attached on the mooring line. To overcome the problem of communication between the two lines during summer (thermocline development), higher rates (up to 4800 Bits/s) were developed. Finally, the underside of the hull instrumentation was replaced with a simpler package.

As line 2 during the first phase proved to be quite efficient, it was decided that it should remain practically as originally developed (Nittis et al., 2003), with the exception of the necessary improvements in order to minimise biofouling. From the very first deployment it became evident that fluorometers and the transmissometers factory calibration was not appropriate, as biological production in the Cretan Sea is significantly lower compared to most other areas where marine observatories are operating. Thus, laboratory experiments were designed and bibliographic information was used in order to perform site-specific calibrations for those optical sensors and to estimate the range of values to be used prior to deployment.

Additionally, all optical sensors were prone to biofouling, considering that the PAR sensors were open to the surrounding water column while the fluorometers and transmissometers were only closed by means of tubing and pump. Based on the experience of the previous deployments during the Pilot Project, biofouling posed a problem for the bio-optical measurements (Drakopoulos et al., 2003), despite the oligotrophy of the Cretan Sea (Tselepides and Polychronaki, 2000). Thus, it was decided that some sort of antifouling technique would have to be applied, in order to improve the quality of the bio-optical measurements during the MFSTEP project. In order to select the most appropriate technique, a pilot study described below was conducted.

3 Pre-target operational period (pre-top)

3.1 Testing anti-fouling techniques

Most of anti-biofouling techniques depend on maintaining a toxic environment to the marine organisms close to the sensors' location. This usually is achieved either with the presence of copper near the sensor (by means of a copper shutter or tubing) or with a bromine solution. Despite the fact that incorporation of copper-shutters is a very promising technology, it could not be used in this case, as the already existing instrumentation did not have a provision for the mounting of such a device. Thus, the methods of bromine solution and copper tubing were tested and compared.

For the open instruments (PAR sensors) two configurations were deployed, one with a copper disk attached bellow the sensor's diffusing bulb and a standard one without any particular action to prevent biofouling. For the rest of the sensors four different configurations were deployed, one with no protection, one with copper tubing, one with bromine and a final one with a combination of both. The copper configuration simply included the replacement of most of the plastic tubing adjacent to the fluorometer and transmissometer (both upstream and downstream) with copper tubing (Ø 10 mm) of similar length. The bromine system incorporated a vented canister with bromine tablets, attached between the fluorometer and the transmissometer, in order to slowly and constantly release bromine solution through diffusion towards both sensors. Erroneous readings were avoided in all sensors by means of flushing for 15 s prior to measurement.

In order to evaluate the above different approaches, an experiment was carried out close to a fish-farm situated off the islet of Patroklos in Saronikos Gulf, Greece. This site was chosen for its relatively eutrophic environment due to intensive fishfarming activities, thus minimizing the duration of the experiment. The experimental site was approximately 50 m eastwards from the fish cages directly influenced by the farm, as indicated by the increased deposition of organic material on the benthic system. A total of two antifouling-test deployments were made.

The four different CTD setups were deployed at the same depth (10 m) in neighboring moorings at a total water depth of 18 m and set to sample hourly. The choice of deploying four moorings instead of one was taken in order to maintain the CTD platforms at the same depth (identical conditions of light/nutrients and chlorophyll) and thus obtain comparable measurements. To aid the interpretation of the results, a current meter was included in one of the moorings and a weather station was set at the aquaculture facility. The first deployment started on 20 May 2003, and lasted until 8 July 2003, when it was retrieved due to the strong algal buildup as observed by in situ scuba.

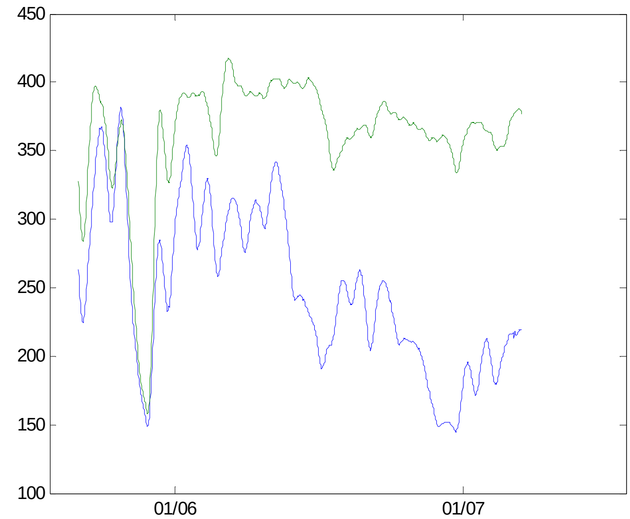


Fig. 3. Lowpass filtered PAR (blue) and incoming solar radiation (green). Note the progressive increase in the distance of the two lines, suggesting the buildup of biofouling on the surface of the PAR sensor bulb.

Analysis of the collected data showed that the open sensors (PARs) behaved in a similar manner regardless of the anticipated toxic environment at the moorings with bromine and copper. An intercomparison of PAR and incoming solar radiation time series after the removal of the daily cycle by means of filtering, showed a decrease of sensitivity of the order of 40% in 50 days, with an accelerating trend towards the end of the deployment period (Fig. 3).

The fluorometers recorded no obvious increase in chlorophyll concentration, despite the external buildup of organisms, with the exception of the one with no protection, which showed an increasing trend towards the end of the deployment. It should be noted here that the chlorophyll concentration as measured from bottle samples in the lab, ranged from 0.06 to 0.09 μg/lt.

The interpretation of the transmissometer's readings was more straightforward. An exponential increase was evident in all configurations that had no bromine canister, indicative of optical window contamination. An interesting result was that the one with the least biofouling was the setup, which incorporated both copper tubing and bromine solution (Fig. 4). This was in contrast to the results reported elsewhere (Manov et al., 2003; Seim et al., 2000).

Upon the retrieval of the moorings, a post-calibration was performed to assess the effects of the biofouling to the sensors, and assess any potential drift.

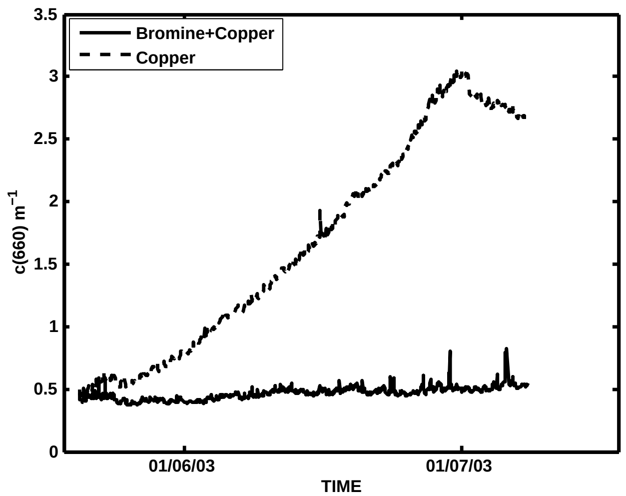


Fig. 4. Beam attenuation coefficient time series for two transmissometers, one with the copper tubing (dashed line) and one with the combined bromine solution and copper tubing (solid line).

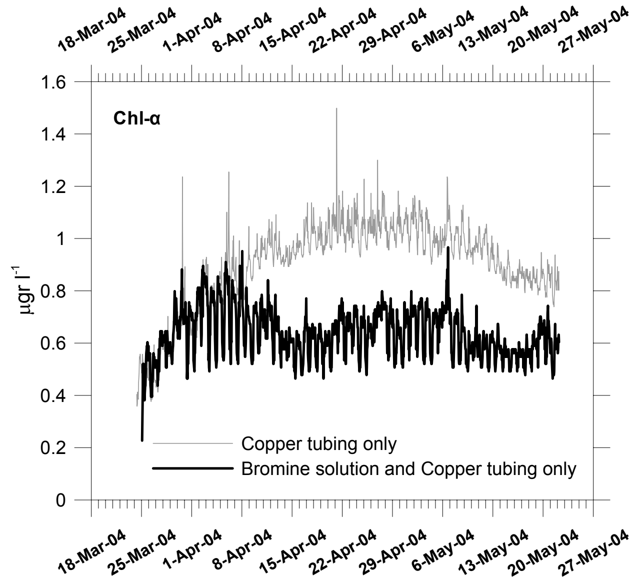


Fig. 5. Comparison of Chl-α fluorometers during the second deployment experiment.

Considering the low content of chl-α experienced during the first deployment, a second trial took place in the same area in spring 2004, aiming to record the spring bloom. The two CTD platforms were deployed in separate moorings at an approximate depth of 7 m, at a water column depth of about 20 m. The deployment took place on 24 March and the recovery on 22 May 2004. The platform S1 was equipped only with copper tubing, while the platform S2 employed both copper tubing and bromide solution.

On producing the engineering units of chl-α fluorescence, the calibration coefficients produced during the 19 May 2003 laboratory calibration experiment, were used. As the calibration coefficients for the 2930 sensor (S4) gave unaccepted values, it was decided to use those for the 2928 (S2) sensor (see Sect. 3.2).

The fluorometers produced almost identical time series for about 10 days, which is the time when the S4 fluorometer measurements started diverging in relation to S1 measurements (Fig. 5). This in effect suggests that the calibration procedure was rather successful. After 3 April the chl-α fluorescence recorded by S4 was systematically lower than S1, showing no trend at all, while the S1 reached a maximum value of 1.2 μg/l before a slow, gradual decrease to lower values. Overall, there was no clear sign of a strong spring bloom which we were hoping to record. The negative trend of the S1 fluorometer measurements during the second half of the deployment period suggests that the measurements were not infested by biofouling.

3.2 Laboratory sensor calibration

During the first phase, soon after each maintenance using the recorded values by the M3A instruments and the reference in-situ measured values, correction coefficients were estimated for the transfer functions that convert the sensors' output to engineering units (Nittis et al., 2003). In all cases, correction coefficients were applied to the oxygen and chlorophyll-α measurements, where the deviation between in-situ and reference measurements was significantly exceeding the sensor's accuracy (0.5–1.2 ml/l for dissolved oxygen, 1.2–3.2 μg/l for chlorophyll-α). In fact, the initial values of chlorophyll-α estimated by the M3A fluorometers were one order of magnitude higher than the reference values (0.6–3.2 μg/l instead of 0.05–0.5 μg/l). This was most probably related to the fact that the sensors had been calibrated by the manufacturer to inappropriate phytoplankton concentrations. As already mentioned, the area of the M3A deployment is characterized by extreme oligotrophism, with at least one order of magnitude lower range of values compared to the instrument's range (0–75 μg/l). Thus, in an attempt to perform site-specific calibrations for this very oligotrophic environment of the Cretan Sea, laboratory experiments were designed and bibliographic information was used, in order to estimate the range of values to be used.

The fluorometers were calibrated, both before the pilot study deployment and after the pilot study deployment. This calibration was based on five samples of local phytoplankton populations, which were nutrient-enriched and cultured for about 10 days, to attain discrete chl-α concentration values. After a 15-min sampling by the fluorescence sensors, a reference value was estimated by extracting phytoplankton by means of filtering and measuring its chl-α fluorescence with a TURNER AU-10 laboratory fluorometer. The fluorescence values were converted to phytoplankton concentration following Yentsch and Menzel (1963).

The fluorometer calibration that was performed the day before the Patroklos deployment is presented in Fig. 6. The chlorophyll-α fluorescence of the cultivated samples, based on the reference measurements, ranged between 0.1 and 0.6 μg/l (Fig. 6c). The output voltages of most of the sensors under calibration exhibited co-varied; however, one of the sensors exhibited several "bad" values that were later attributed to the presence of an air-bubble in the closed circuit providing water to the sensors (Fig. 6b). Comparing the range of the chl-α values obtained using the factory calibrations (Fig. 6a) with the range obtained after applying the calibration coefficients obtained with the presently described method (Fig. 6d), it becomes evident that the calibration was a necessary exercise, as the use of the factory calibrations would result in a severe overestimation of the phytoplankton concentrations during the experiment. Thus, considering the above result, it was decided that the newly-obtained calibration coefficients would be adopted. Furthermore, it is interesting to note the unstable behavior of the fluorometer with s/n 2729, and the zero values that periodically sensor s/n 2730 produced. The latter were attributed to air bubbles trapped in the tubing in the vicinity of the fluorometer sensor, while the unstable behavior of the 2729 sensor (which behaved well throughout the field experiment), was most likely due to a rather inefficient experimental design. In order to facilitate and accelerate the whole process, the fluorometer measurements were performed on the same control solutions. Thus, a single water circuit was designed, connecting the tubing of all four CTD platforms, and forcing the same solution to be sampled by all sensors. As 2729 sensor was the last in the row, it is assumed that the phytoplankton had lost its fluorescence responsiveness as a result of the three previous successive light stimulations.

Transmissometers were post deployment calibrated by the standard method of blocking the receiver and obtaining a dark reading of output voltage and by taking several voltage readings in de-ionized water to obtain a clean water offset.

4 Target operational period (top)

4.1 Periodic maintenance

As already mentioned, a significant aspect right from the start of the project was the minimisation of cost, achieved mainly through the minimization of maintenance effort. The three line configuration approach adopted could ensure the low operation cost, as only a relatively small part of the equipment had to be frequently removed. More specifically, for line 1 hosting the buoy a bimonthly servicing schedule was decided only for the buoy sensors with an on-site procedure, while for the CTs the servicing interval due to the absence of fouling was limited to battery replacement every 12 months. Since the sensors on line 2 were in the euphotic zone, fouling was expected to significantly affect the accuracy of the

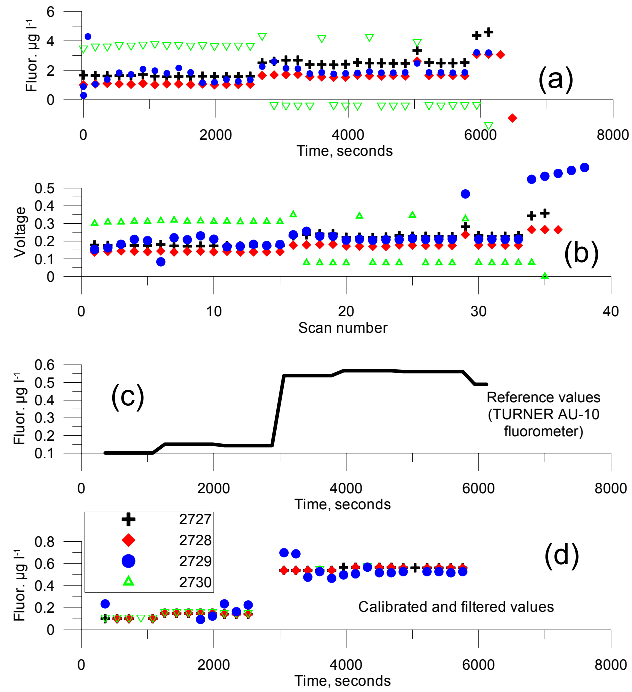


Fig. 6. Fluorometer calibration results are presented, as time series of **(a)** chl-α concentration of the alternating control solutions based on factory calibration values, **(b)** corresponding voltage of the fluorometers, **(c)** reference values obtained via the laboratory method and (d) calibrated and filtered values.

measurements prohibiting long deployment intervals. Additionally, the wet chemistry procedure of nitrate analysis and the 3-h sampling frequency of all sensors determined a bimonthly maintenance interval. Although the design was such that during servicing the full line had to be recovered and redeployed, the whole operation could be carried out with a small R/V, such as the 26 m Philia (http://www.hcmr.gr/english_site/services/shi_sub_rovs/philia.html). For line 3 the 30-min sampling program chosen, forcing an approximate service interval of 6 months mainly for battery replacement, data downloading and cleaning. Additionally for emergency visits the 5.25-m rigid hull inflatable IOLKOS was used.

In the course of phase 1 and phase 2 of the MFS project 13 scheduled and 15 emergency visits were performed (Table 1). In detail, the duration of the scheduled maintenance trips was three days, with the first one dedicated to the retrieval of line 2 (and line 3 when applicable). Once on site, line 2 was acoustically released and brought into the deck. Following all instruments, cables and floating spheres were thoroughly cleaned with the use of mild detergent and low-pressure washing gun. Parallel to the above, water samples from the depths of 0, 35, 40, 60, 85, 110 and 200 m were collected for dissolved oxygen and dissolved nutrients, while a CTD profile (conductivity, temperature, pressure, dissolved oxygen, fluorescence, turbidity and PAR) down to 1000 m

Table 1. Visits to M3A.

Vessel	DATE	TYPE	PROBLEMS
Aegeao	27/1/00	Scheduled	Start of MFSPP Line 3 was not deployed due to ADCP malfunctioning
Philia	9/2/00	Emergency	Redeployment of line 2
Philia	2/3/00	Emergency	The serviced ADCP was deployed (line 3)
Philia	4/3/00	Scheduled	Due to sensor problems CTD S/N3 was removed.
Iolkos	22/4/00	Emergency	After a problematic communication with the buoy it was discovered that the central mast with the antennas was broken.
Iolkos	24/4/00	Emergency	The broken part mast was removed and the antennas secured on the remaining structure but not the wind generator, weather station probes, etc.
Iolkos	28/4/00	Emergency	Communication problems with ARGOS
Iolkos	9/5/00	Emergency	Due to decreased quality transmittance of data from line 1 to the main computer on board the buoy an underwater connector was replaced
Iolkos	12/5/00	Emergency	The onboard PC was removed for maintenance
Philia	15-17/5/00	Scheduled	The oxygen sensors at CTD S/N3 & 4 were not working
Iolkos	1/6/00	Emergency	PC communication problems
Iolkos	5/7/00	Emergency	The surface buoy broke off and was recovered at the east Crete.
Philia	10/7/00		Due to ship traffic the top part of line 1 was submerged to 20–30 m by adding weights.
Philia	31/7–2/8/00	Scheduled	Due to ADCP malfunction mooring line 3 was not deployed
Philia	31/8/2000	Emergency	Deployment of line 3
Philia	29–31/10/00	Scheduled	CTD malfunctioning sensors – S/N3 (40 m) turbidity, PAR and oxygen, – S/N1 (65 m) oxygen and PAR, – S/N 2 (90 m) oxygen and PAR – S/N 4 (115 m) oxygen, PAR, turbidity chl-α. Also, the nutrient analyser, due to a falt in the syringe did not perform any measurements.
Philia	6/3/2001	Scheduled	Maintenance of line 2
Philia	19-22/4/01	Scheduled	The nutrient analyzer was not functioning and could not be fixed, while there were problems with CTD S/N 3 at 40 m which had no measurements with only exception the Chl-α sensor.
Aegaeo	27/11/01	Scheduled	End of MFSPP
Aegaeo	20/7/04	Scheduled	Start of MFSTEP
Iolkos	4/8/04	Emergency	The onboard PC was rebooted
Iolkos	17/9/04	Emergency	The communication was lost
Philia	1–5/11/04	Scheduled	Apart from the maintenance of line 2 the surface buoy was removed
Philia	6-8/4/05	Scheduled	The serviced buoy was attached once more in line 1
Iolkos	20/4/05	Emergency	Small repairs on surface buoy
Iolkos	25/4/05	Emergency	The onboard PC was rebooted
Philia	22/10/05	Emergency	Line 1 had broke off and the was recovered in the East Crete
Philia	16-22/11/05	Scheduled	Line 3 was removed and from line 2 CTD S/N1 was replaced with a SeaCat sensor from line 1.

was performed. Additionally, all sensors on board the buoy were cleaned by divers who also examined the anchoring and cable systems. Once at Heraklion harbour, the 4 CTDs and the nutrient analyzer were transported into HCMR facilities for further maintenance and downloading of data.

During the second day at the HCMR facilities, the fixed oxygen samples were analyzed with the Winkler (Carpenter, 1965) method while the nutrient analyzer was cleaned and data were downloaded. The syringe and the inlet – outlets were dismantled and washed with mild acid to remove any organic deposits while the colorimeter was flushed with a mild soap. The analyzer bags were filled with fresh chemicals and a new cadmium column was prepared. The efficiency of the colorimeter was tested in the lab against known concentration solutions and once satisfactory, the sampling protocol was programmed. Data from the CTDs and Nireus was downloaded and all sensors were dismantled, carefully cleaned and serviced according to the manufacturer's instructions. On several occasions, malfunctioning sensors as revealed by the acquired data had to be removed for servicing, either on the spot or sent to the corresponding factory. Finally, all sensor batteries were evaluated and when appropriate replaced with new ones. Once serviced, instruments were transported into R/V Philia where the line was re-assembled and set to standby (instruments were not powered).

Early in the third day before departure and after a final check, all instruments were activated, in order to have the same reference measurements prior to the deployment.

During the following days nutrients and chl-α concentrations were estimated at the HCMR chemistry lab using standard methods. A Turner 00-AU-10 fluorometer was used for the chlorophyll-α analysis. Fluorescence was converted to chlorophyll-α using the formula of Yentsch and Menzel (1963). Temperature, salinity, light attenuation and PAR data

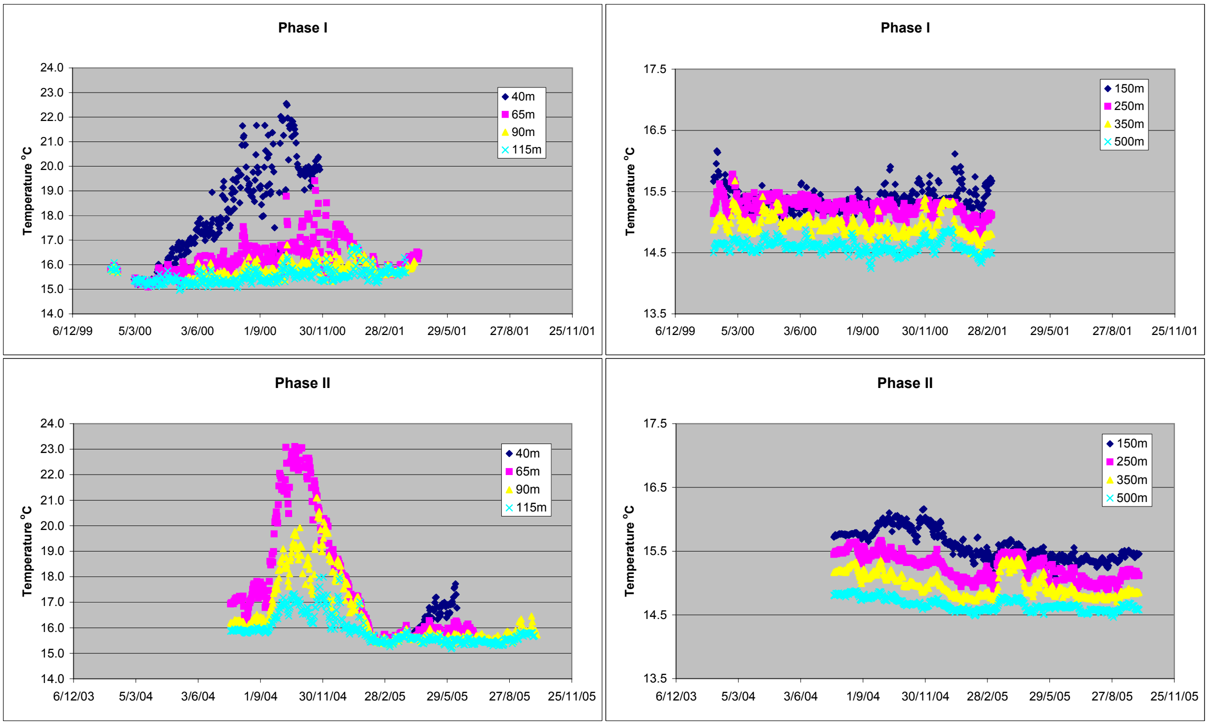


Fig. 7. Temperature measurements at various depths during Phase I and Phase II of MFS project.

were compared against reference CTD measurements carried out by the SBE-25 of R/V Philia and the SBE-911 of R/V Aegaeo, respectively. Salinity measurements of the reference CTD casts were corrected against a salinometer analysis of the water samples.

Emergency trips were mainly done with the HCMR inflatable IOLKOS for a number of causes, most of which were related to communication problems.

4.2 Problems encountered

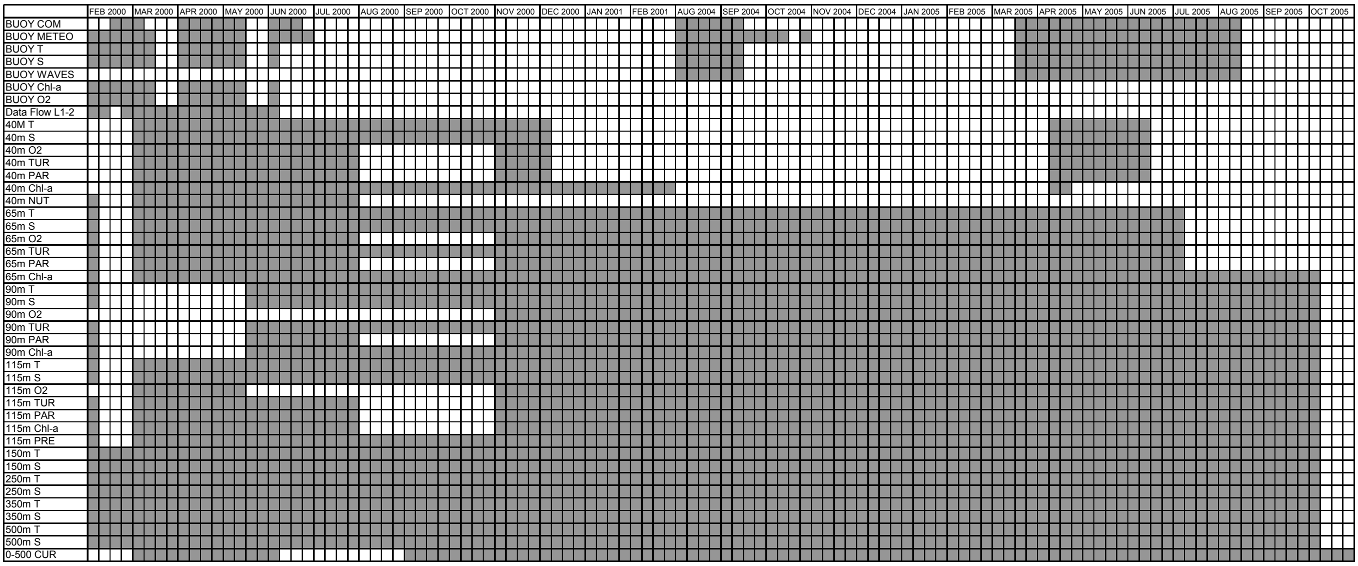
The main problem during the first phase of the project was caused by a false connection of the umbilical cable with the surface buoy which eventually broke off (Nittis et al., 2003).

Apart from the problematic Argos antenna, all light sensors suffered from biofouling while PAR sensors also exhibited problems associated with their amplifiers.

Soon after the start of the second phase of the project, there were problems associated with the bi-directional data transfer and remote reprogramming of the buoy, causing inefficient data transfer. Although these problems were successfully solved on site during an emergency visit, soon after the communication was completely lost. Thus in the course of a scheduled maintenance the buoy was removed and transferred to HCMR for servicing. Apart from a couple of flooded solar panel junction boxes, which were easily repaired, the main problem of the buoy was a destroyed PC motherboard. Since a replacement part was not available, the deployment of the buoy was postponed until the next scheduled maintenance. There were also problems with Line 2, and in particular, with the recently factory serviced nutrient analyser which once more was flooded due to a faulty gasket at the syringe piston, making it impossible to recover the data. To avoid a gas buildup inside the Nireus PC battery housing during the second phase, bleeding valves were installed, one of which proved to be faulty, thereby flooding the container. Thus, as there were no data stored in the underwater PC, all data were downloaded from each individual CTD with the exception of the top one (S/N 3), in which the batteries were completely drained, erasing all measurements. This problem with drained batteries persisted for most of the second phase for the top of the line CTD (S/N 3), as well as for the S/N 1 at 60 m and S/N 4 at 110 m during the last deployment, exhibiting a serious disadvantage of the particular instruments as the data are not stored in a flash-type memory.

Finally, in October 2005, 14 months after the first deployment the buoy once more broke loose and was found in the eastern part of Crete, before being washed ashore. Surprisingly, the 16-mm wire rope was clean-cut at approximately 600-m depth, losing 12 pairs of floating spheres and two acoustic releasers. However, all four CTs mounted on the inductive wire rope were recovered in very good condition and all data were downloaded successfully.

Table 2. System performance (white colour indicates absence or bad data).



5 Buoy performance

In Table 2, the overall performance of the M3A system during the two phases is presented. It is evident that the most reliable instruments were the four CTs, producing non-stop measurements of temperature and salinity in contrast with the nitrate analyser, which had a working period of approximately 4 months. Although the latter was one of the first instruments produced and unavoidably had a number of defects, the data produced were exceptionally, good even for the oligotrophic Cretan Sea. Additionally, most of the problems related to the optical sensors during the first phase were successfully solved, while the serious disadvantage of the CTDs relying solely on power for data storage, resulted in the loss of significant data. The surface buoy was proved to be the weakest part of the system, since it had the longer periods of inactivity due to a malfunction of different subcomponents. Since this buoy has already extended its expected lifetime, its upgrade or replacement is among the highest priorities for the next few years. Finally, the line-3 ADCP had an overall very good performance and provided a long time series of current profiles in the 0–500 m layer.

The temperature time series at various depths are shown in Fig. 7. Comparing the top part of the water column during the two phases, one can observe a clear warming of the upper 100 m between the periods. Such variability can be justified by the fast response of the seasonal thermocline to interannual variability of atmospheric forcing. The respective differences in the lower part (100–500 m) of the water column are smaller but an increased temporal variability and a stronger stratification is presented in phase 2 compared to phase 1. This can be attributed either to interannual variability of vertical mixing and diffusive processes (i.e. reduced intermediate water formation during the previous winter(s)) or to shorter time scale variability of the mesoscale features (horizontal displacement or intensification of the cyclonic-anticyclonic dipole) that control the dynamics of the M3A site in the Cretan Sea (Cardin et al., 2003).

The calibrated chlorophyll-α measurements from the four fluorometers in line 2 during the two phases are shown in Fig. 8. A noticeable feature is the reduced variability in all chl-α measurements during the second phase, although the data at 40 m, which is the depth expected to show such phenomena, is rather inadequate.

One of the key issues as already mentioned was the minimisation of cost, which eventually will justify this approach over the more traditional ship expeditions. The costs (Table 3) can be divided into three major categories, with the initial costs separated into a) capital costs, including the surface buoy and the necessary equipment and b) the initial deployment costs, which include three days ship time with R/V Aegaeo, and the associated personnel cost. The second category includes the annual expenses mainly depending on the servicing frequency. In this case, these are separated into a) the calibration costs, b) maintenance costs, (considering 6 trips per year with R/V Philia, each one with a duration of three days, two of which include ship time), consumables and personnel, and c) communication costs. The last category are the unforeseen emergency costs which include daily visits with the inflatable R/V Iolkos covering the fuel and the personnel.

Table 3. Cost analysis.

COSTS		Euros
INITIAL COSTS	Capital Costs	
	Surface buoy	120,000
	Equipment	252,000
	Initial Deployment Costs	
	R/V Aegaeo	12,000
	Personnel	1,000
	TOTAL	**385,000**
ANNUAL COSTS	Calibration Costs (1 year)	
	Consumables	1,800
	Personnel	11,400
	Maintenance Costs (1 year)	
	R/V Philia /d	24,000
	Consumables/maintenance	6,000
	Personnel/maintenance	7,800
	Communication Costs (1 year)	
	GSM	960
	Iridium	4800
	Argos	1440
	TOTAL	**58,200**
UNFORESEEN COSTS	Emmergency Costs	
	R/V Iolkos	120
	Personnel	100
	TOTAL	**220**

6 Conclusions

During the pilot phase of the Mediterranean Forecasting System, a prototype observing system was designed, developed and operated in the Cretan Sea, aiming towards the continuous recording of multi-parametric data. Such time series are a valuable tool for both the insight into the system dynamics, as well as a prerequisite for model development, calibration and validation. The low maintenance cost, a key aspect of the project, forced one towards a modular design, allowing different servicing intervals between the various parts of the system. Thus, only the necessary components were maintained at each visit, avoiding the use of large and expensive vessels and at the same time ensuring a fast response to system failures. The main problems encountered were associated with communication and data transfer both between lines 1 and 2 and between line 1 and HCMR. The other significant source of the problems was the optical sensors which were found to be very sensitive to biofouling and in particular, the light transmittance sensors.

With the significant experience gained during the 2000–2001 deployment, the project moved to the second phase with three major aims, the first of which was the improvement of both underwater and aerial communications. Thus, under-water acoustic bi-directional modems and IMC modems were used, while the underwater hardwired network was embedded into the buoy container and attached on the mooring line. To overcome the problem of communication between the two lines during summer (thermocline development), higher rates (up to 4800 Bits/s) were developed. For

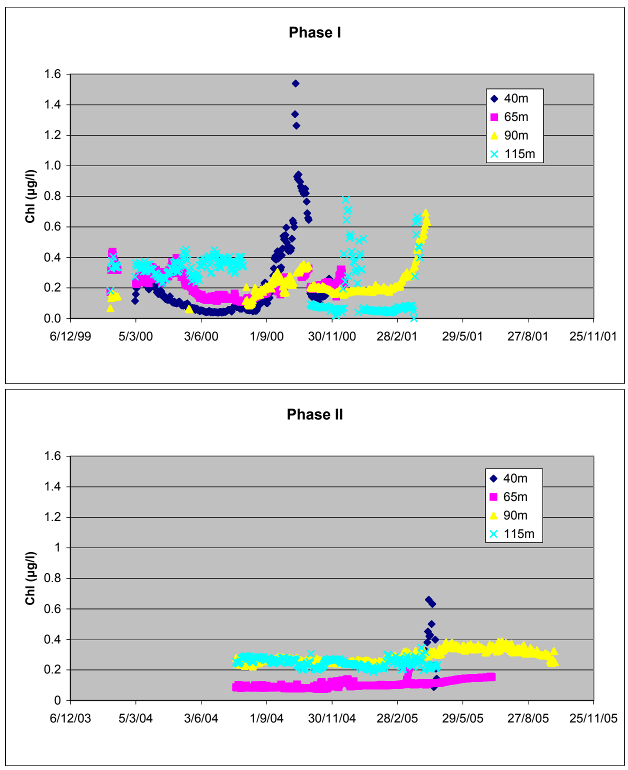


Fig. 8. Chlorophyll-α measurements at various depths during Phase I and Phase II of MFS project.

the aerial communication, a tested and very reliable technology used on the 11 Seawatch buoys that operate in the Aegean Sea in the framework of the Poseidon project (Nittis et al., 2001) was selected, transmitting all data through the Inmarsat-C satellite. The disadvantages of the new system were the increased energy requirements and the increased running cost, but at the same time there was the possibility of two-way communication, an important feature, as minor problems (re-programming) could be solved from HCMR, thus avoiding on-site visits.

The second aim was the redesign of the surface buoy, thereby increasing modularity and flexibility and at the same time decreasing complexity and servicing requirements. Particular attention was paid in the optimisation of the hull's hydrodynamic performance.

The final aim was the minimisation of the biofouling effect, especially for the optical sensors. To overcome this problem new methods and anti-fouling techniques have been developed worldwide, such as the generation of biocide chlorine compounds on tin oxide coating, the use of UV pulses, the incorporation of cooper shutters, the use of copper tubing and the bromide pumping technique, each one with its advantages and disadvantages. As not all of the above methods were applicable, a pilot field study was performed with the techniques of bromine solution and copper shielding (tubing). The short experimental study suggested that a combination of copper tubing and bromine solution would be more efficient than each one separately; therefore, this was selected for application to the M3A mooring. This pilot test demonstrates that the M3A system could be used in the future as a test bed, where prototypes and new methodologies are evaluated. Parallel to the above, several quality control procedures accompanied the deployment of the M3A platform during the second phase. The oligotrophy of the Aegean Sea dictated the need to ignore factory calibrations of the fluorometers, and to perform site-specific laboratory calibrations of the sensors. This procedure was proved necessary and produced calibration coefficients that gave results comparable to the measurements obtained with the laboratory analysis method.

It should be noted that in the course of several projects involving moorings, like POSEIDON (Nittis et al., 2002; Nittis et al., 2001), MFSTEP and INTERPOL (Tragou et al., 2005), we have encountered the problem of improving the quality of the mooring time series through post-processing or comparison with reference measurements obtained through higher accuracy methods in the field. Based on previous experience from field hydrographic measurements, where salinity samples from bottles are routinely used as reference measurements to improve the quality of CTD data, a first approach is to follow a similar methodology for mooring measurements. This approach would consist of collecting field samples from the instrument depths during the frequent maintenance visits, and after the retrieval of the complete time series produce a least-squares fit between the mooring measurements and the reference values produced from the higher accuracy laboratory methods. This approach was abandoned from the very early stages of our involvement in the quality assurance of mooring measurements, as the measurements made at a single depth usually exhibit small variability when compared to the potential range of the parameters in the area. This problem is rectified by the fact that the periodic maintenance visits provided a few reference samples that, in most cases, covered a very small range, even compared to the range of values of the collected time series. Thus, this approach leads to a bad estimate of the correlation slope between instrument and reference. To overcome this problem, it was decided that for mooring measurements it is imperative to perform pre-deployment and post-retrieval calibrations, if possible, in the laboratory, thus covering the whole possible range of parameters under consideration.

Thus, in our experience, post-processing can be used as an assessment for the characterization and flagging of measurements, but not really for the recuperation of the time series. Even this process, however often, presumes some hypotheses (like long-term stationarity) that may not necessarily hold, and it might be unwise to adopt them in the process of just producing a reliable time series. Some parameters require specific treatment. Transmissometers often exhibit rather linear drifts, which may be easily corrected if such intervention is justified by field measurements and the subsequent deployment of a "clean" sensor. The same holds for conductivity measurements. Fluorometers, however, exhibit a less linear behaviour. Very often, a shift at a new "background" value follows a recorded bloom, which may influence the effective geometry of the sensor's window. An attempt to recuperate such measurements would involve the use of a combination of removing a linear trend and a step function. However, as mentioned above, in order to follow such a procedure in a justified way, while involving as few assumptions and perceptual models as possible, it is imperative to have high-frequency reference measurements, unaffected by biofouling. Only in the case of near-surface waters it is possible to correlate with time-series provided by biofouling-free satellite measurements, in order to remove the drift of moored instruments like fluorometers, and even in this case, the newly-produced values should be flagged as "estimated".

Analysis of the collected data during the two phases of the MFS project indicates the highly variable character of the Cretan Sea. The circulation in the Cretan Sea is dictated by the combined effect of two gyral features, an anticyclonic eddy in the west and a cyclonic eddy in the east of the M3A (Georgopoulos et al., 2000; Theocharis et al., 1999). Additionally, there are a number of water masses, with the Modified Atlantic Waters (MAW) occupying the surface layers, the Cretan Intermediate Water (CIW) beneath it and the very important Transient Mediterranean Water (TMW). The latter is an old water mass characterised by high nutrient and low oxygen concentrations, that under certain circumstances (increased eddy dipole intensity) can enrich the euphotic zone, initiating small-scale phytoplankton blooms (Tselepides and Polychronaki, 2000). The above features result in a highly variable environment with phenomena at very short time scales, almost impossible to capture with traditional sampling trips, thus demonstrating the importance of continuous, multidisciplinary monitoring.

One of the common issues related to ocean observatories is the limited use of the data produced by the scientific community. This problem is both due to the limited access to the data and to the fact that the data needs of the modellers and/or the experimentalists are rarely taken into account during the design of the platforms. In the case of the M3A this first issue has been adequately tackled by making widely available all data sets through the project web site. Additionally, during the system design phase, there was significant feedback between the possible users as to where and what sensors should be used. As a result, the data has been used for both process studies that improve our understanding of the Mediterranean Sea functioning (Cardin et al., 2003) and for the development of ecological models that simulate its ecosystem variability (Allen et al., 2002; Petihakis et al., 2002; Siddorn and Allen, 2003; Triantafyllou et al., 2003b). A very important aspect of the data produced is its use in assimilation methods developed by HCMR, in order to be able to use real-time M3A data into the MFS operational forecasting system (Hoteit et al., 2004; Hoteit et al., 2005; Hoteit et al., 2003; Triantafyllou et al., 2003a).

There are a number of marine research topics that observation systems will offer a great deal in the future, such as the high frequency study of biogeochemical processes and in particular, the influence of anthropogenic perturbations in the ecosystem dynamics (Nittis et al., 2003), the ocean – climate coupling and the understanding of carbon dioxide sequestration and the model development. The three-dimensional modelling of marine ecosystems is lagging behind the modelling of marine physics, because it requires robust hydrodynamic models, adequate computing resources and most importantly, adequate field data. Additionally, in order to achieve predictive capabilities, deterministic ecosystem models need to be updated with biological, physical and chemical data at relevant space-time scales. Unfortunately, in most areas, long, high-frequency time series, which are crucial for the models as system parameters, do not exist. A network of ocean observatories collecting a wide range of high-resolution measurements, along with the capability of adaptive sampling of environmental events, would greatly enhance the ability of researchers to develop and improve models of oceanographic processes (Isern and Clark, 2003).

The overall experience from the two phases of the MFS project suggests that a continuous operation of the M3A system is feasible at relatively low cost, although new developments and improvements in particular parts remains an open issue. During the last years important technological solutions have been produced by the continuously growing research industry. Thus, more and more parameters can nowadays be measured both on board platforms and underwater in a wide range of conditions and with rather long servicing intervals. Although there is still a great deal on this research topic unknown, especially on biochemical parameters, the future is very promising.

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